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Manstretta

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(54) **HIGH PRECISION POWER DETECTOR**

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(51) **Int. Cl.**

G05F 3/04 (2006.01)
G05F 3/16 (2006.01)

(52) **U.S. Cl.** **323/312**; 323/907

(58) **Field of Classification Search** .... 323/268, 323/271, 312, 315–317, 907; 324/105, 120, 324/123 R, 123 C; 330/2, 252, 253, 256, 330/259–261, 289, 290

See application file for complete search history.

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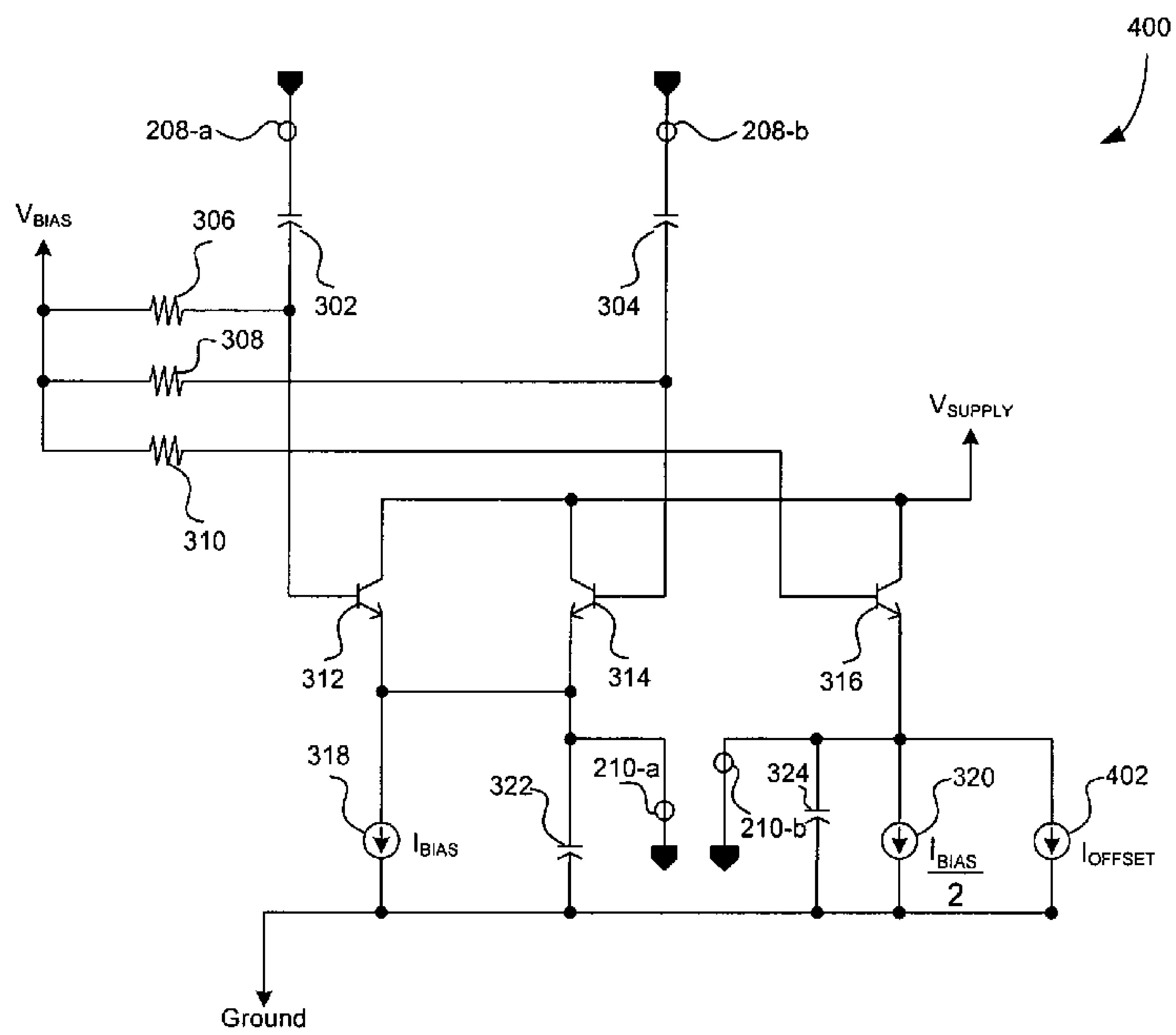
(57) **ABSTRACT**

A power detector having temperature compensation for improved measurement performance includes a pair of rectifier transistors coupled to a differential input signal biased by a first temperature dependent current. An output of the pair of rectifier transistors provides a first component of a differential DC output signal. The first component of the differential DC output signal includes a DC voltage proportional to an amplitude of the differential input signal plus an offset voltage. The power detector further includes a reference transistor biased by a reference current. The reference current includes a second temperature dependent current and a temperature independent offset current for temperature compensation. An output of the reference transistor provides a second component of the differential DC output signal that includes a reference voltage. The temperature independent offset current is adjusted such that the reference voltage substantially equals the offset voltage, thereby improving the precision of the power detector.

19 Claims, 6 Drawing Sheets



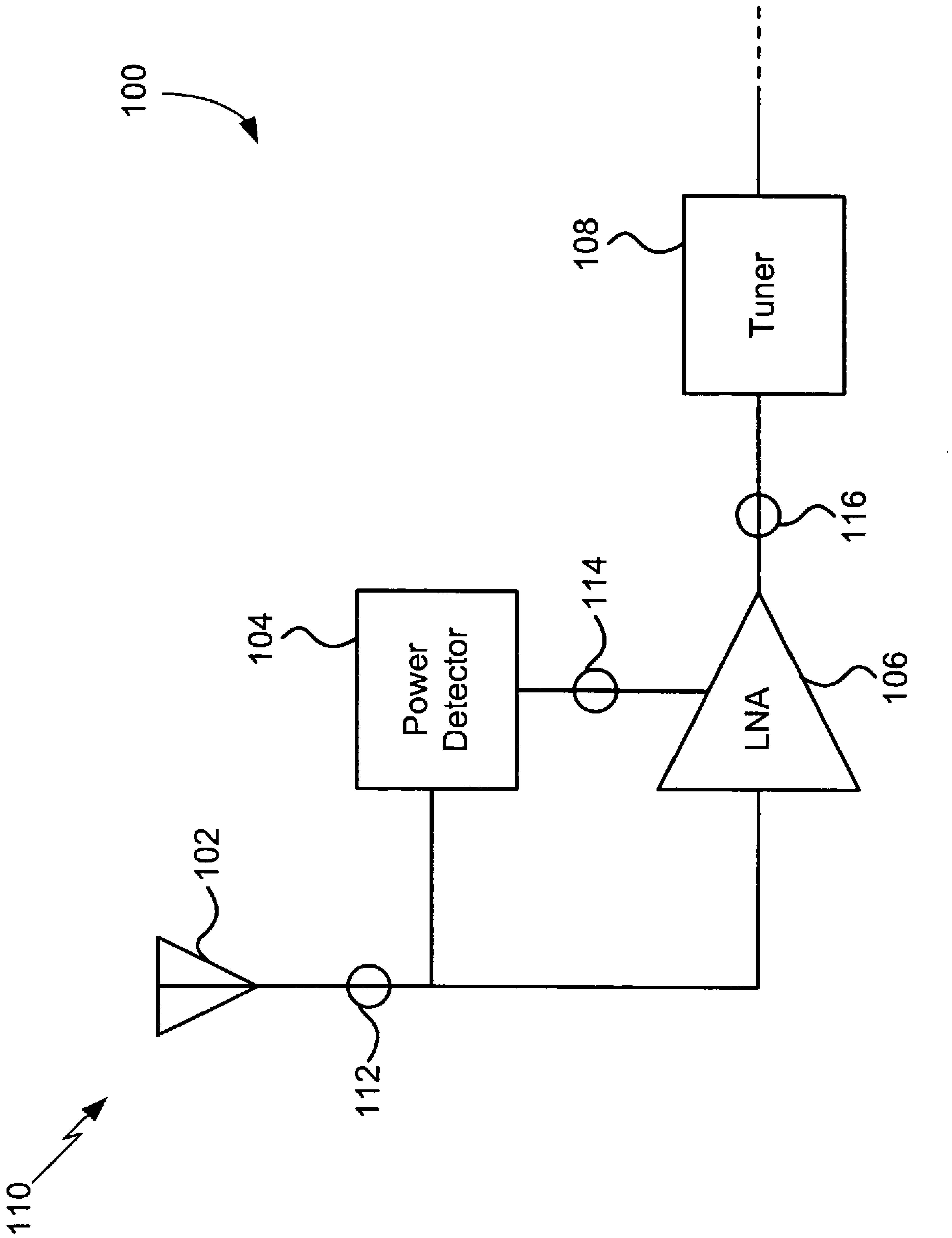


FIG. 1
Conventional Art

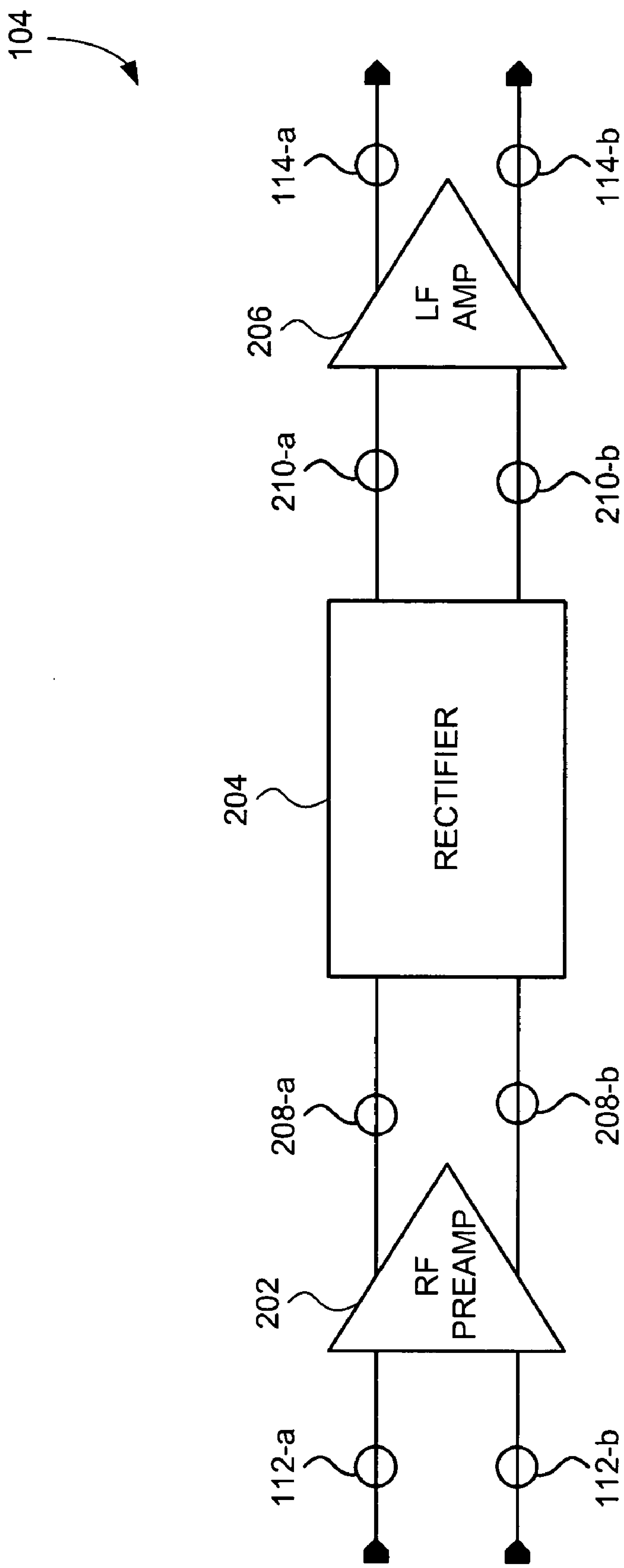


FIG. 2
Conventional Art

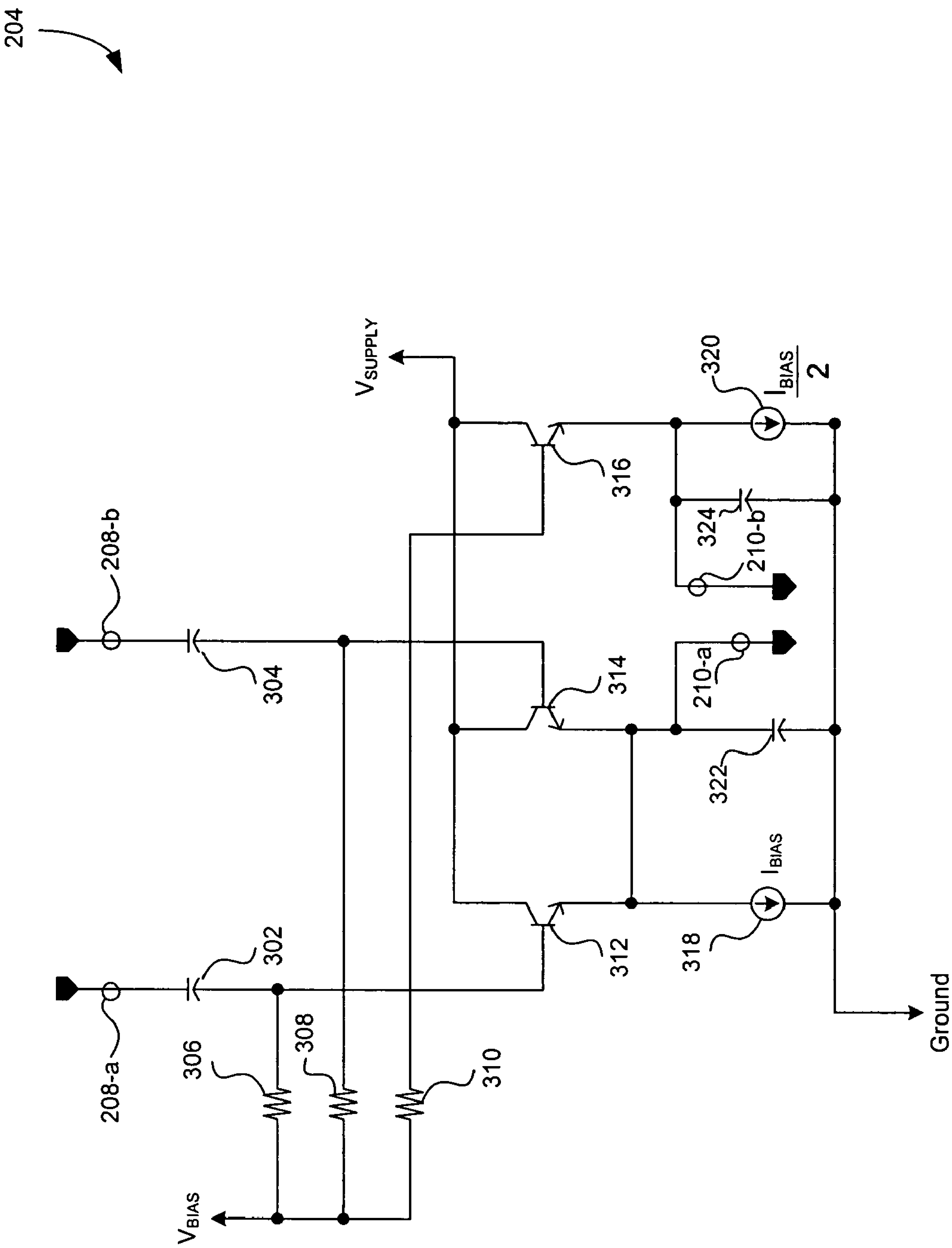


FIG. 3
Conventional Art

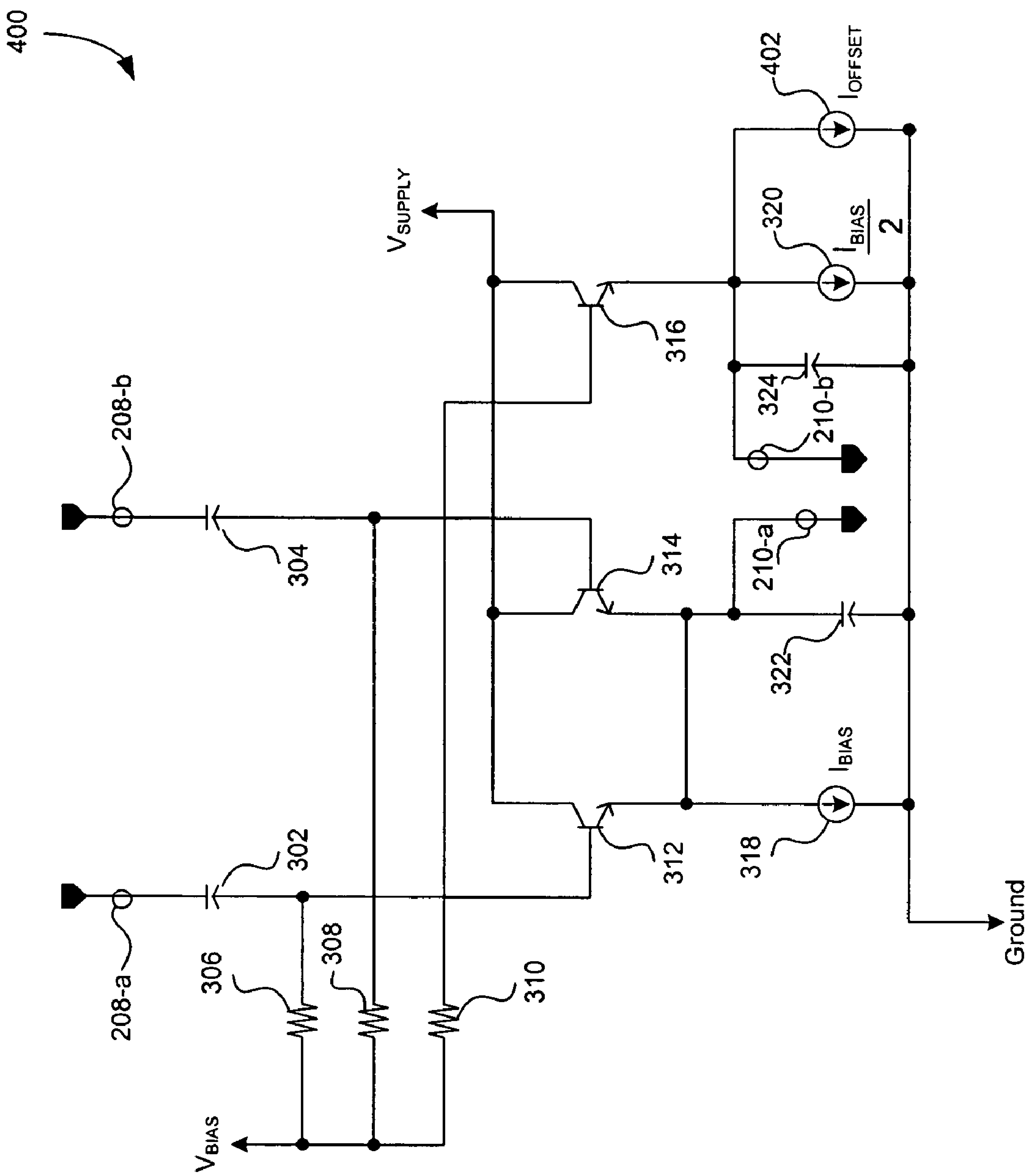

400
208-a
208-b
302
304
306
308
310
312
314
316
318
320
322
324
210-a
210-b
402
V_{BIAS}
V_{SUPPLY}
I_{BIAS}
$\frac{I_{BIAS}}{2}$
I_{OFFSET}
Ground

FIG. 4

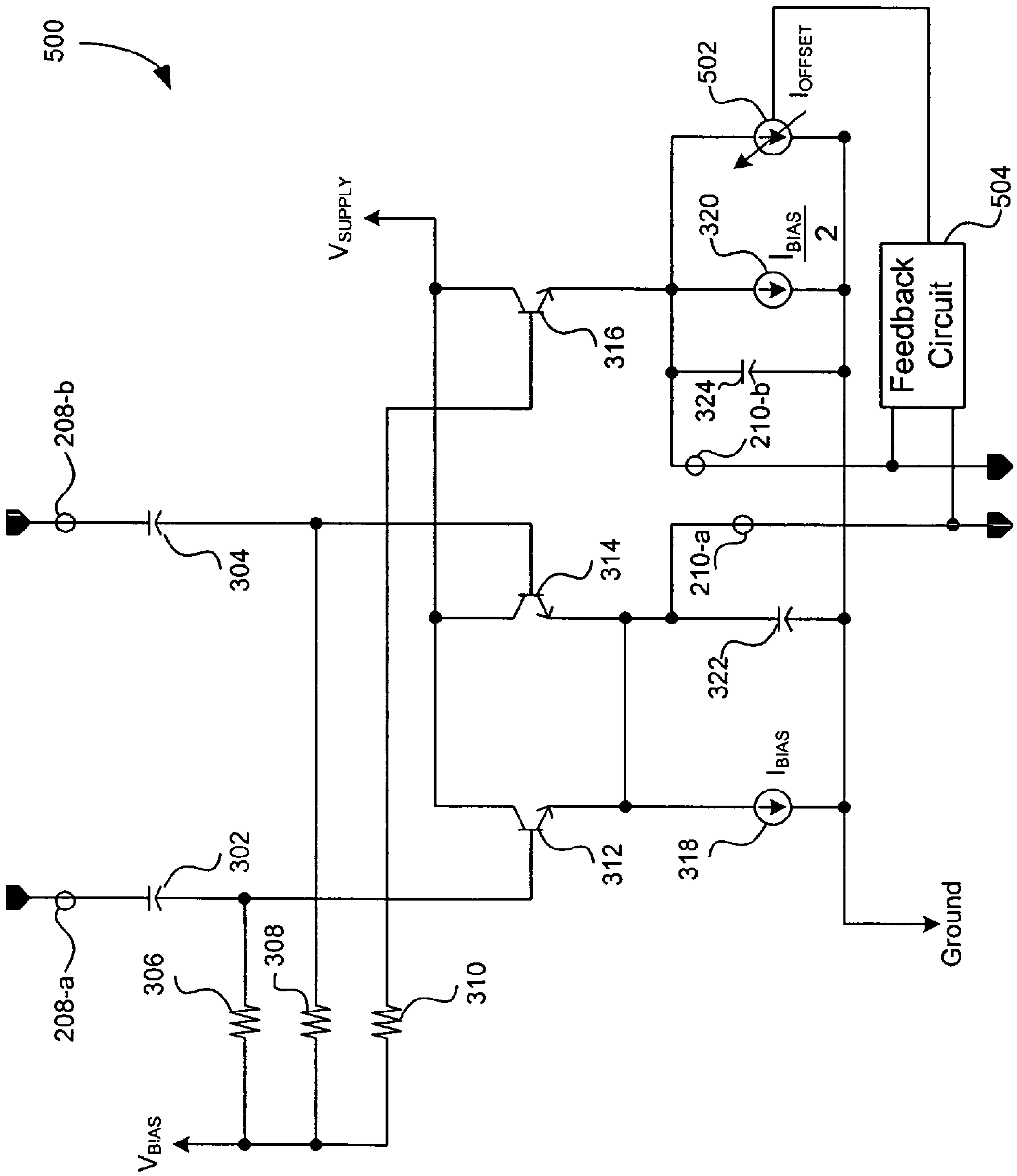

500
208-a
208-b
302
304
306
308
310
312
314
316
318
320
322
324
210-a
210-b
502
504
V_{BIAS}
V_{SUPPLY}
I_{BIAS}
$\frac{I_{BIAS}}{2}$
I_{OFFSET}
Feedback Circuit
Ground

FIG. 5

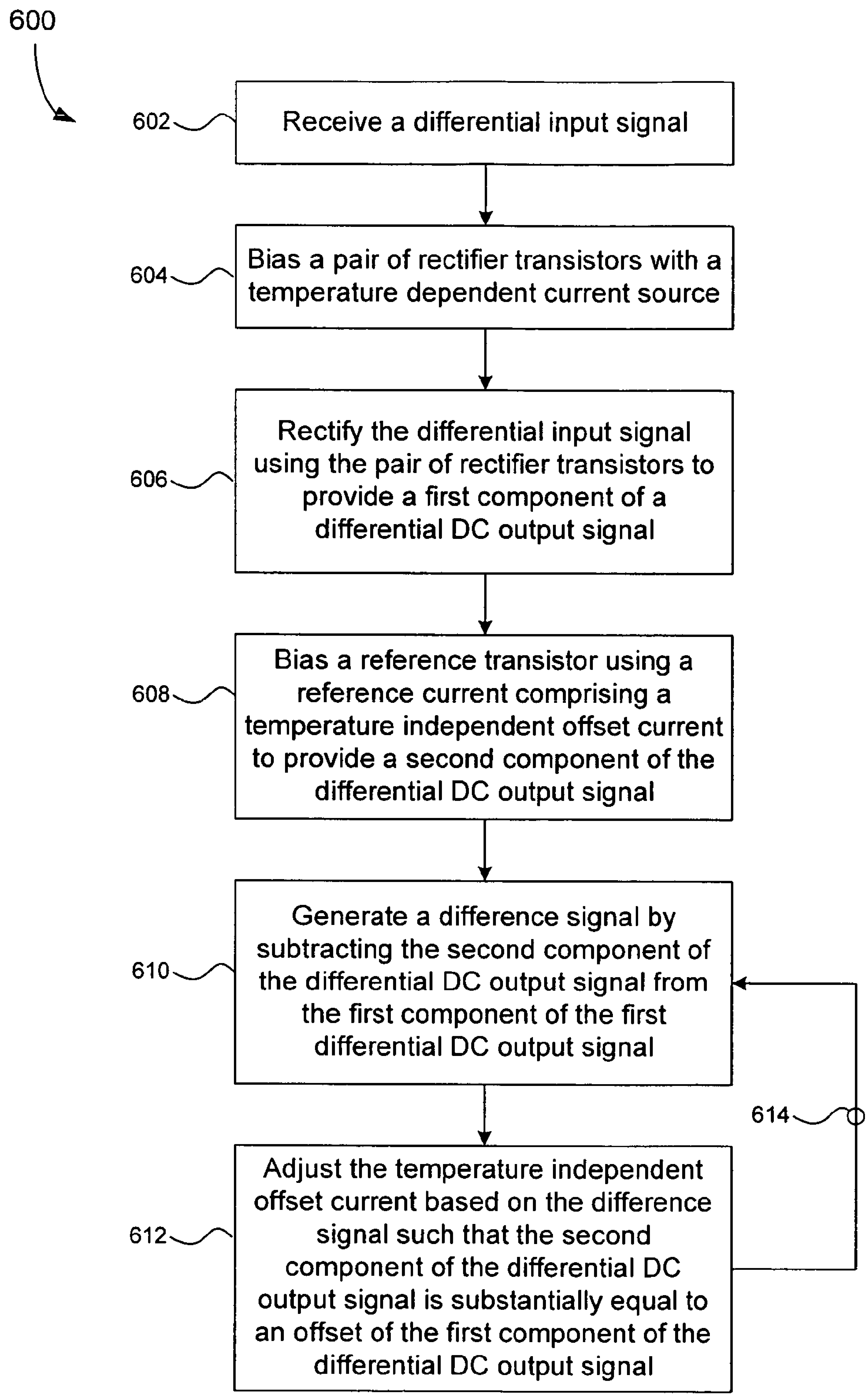

600
602
Receive a differential input signal
604
Bias a pair of rectifier transistors with a temperature dependent current source
606
Rectify the differential input signal using the pair of rectifier transistors to provide a first component of a differential DC output signal
608
Bias a reference transistor using a reference current comprising a temperature independent offset current to provide a second component of the differential DC output signal
610
Generate a difference signal by subtracting the second component of the differential DC output signal from the first component of the first differential DC output signal
614
612
Adjust the temperature independent offset current based on the difference signal such that the second component of the differential DC output signal is substantially equal to an offset of the first component of the differential DC output signal

FIG. 6

HIGH PRECISION POWER DETECTOR

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application No. 60/635,175, filed Dec. 13, 2004, which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to power detectors. More specifically, the present invention provides a power detector having temperature compensation for improved measurement performance.

2. Background Art

Power detectors measure the amplitude or power of an input signal. The precision of a power detector is limited by linearity errors and process and temperature variations. The constituent components of a power detector typically exhibit a strong dependence on temperature, especially at low input power levels. Therefore, as temperature varies, the output measurement provided by a power detector can fluctuate considerably for a given constant input amplitude. This limits the range of input amplitudes that can be accurately measured to relatively high levels where the effects of temperature variation are less pronounced. Further, input signal bandwidth decreases if low power input signals require increased amplification prior to detection.

BRIEF DESCRIPTION OF THE DRAWINGS/FIGURES

The accompanying drawings illustrate the present invention and, together with the description, further serve to explain the principles of the invention and to enable one skilled in the pertinent art to make and use the invention.

FIG. **1** illustrates a conventional wireless receiver.

FIG. **2** illustrates a conventional power detector.

FIG. **3** illustrates a conventional rectifier.

FIG. **4** illustrates an embodiment of a rectifier of the present invention having temperature compensation for improved measurement performance.

FIG. **5** illustrates an alternative embodiment of a rectifier of the present invention using feedback to provide temperature compensation for improved measurement performance.

FIG. **6** provides a flowchart that illustrates operational steps for adjusting the temperature compensation of a rectifier of the present invention to improve measurement performance according to the present invention.

Features and advantages of the invention will be set forth in the description that follows, and in part will be apparent from the description, or may be learned by practice of the invention. The advantages of the invention will be realized and attained by the structure and particularly pointed out in the written description and claims hereof as well as the appended drawings.

It is to be understood that the following detailed description is exemplary and explanatory and is intended to provide further explanation of the invention as claimed.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** illustrates the front-end of a conventional wireless receiver **100**. The conventional wireless receiver **100** includes an antenna **102**, a conventional power detector **104**, a low noise amplifier (LNA) **106** and a tuner **108**. The antenna **102** receives a transmitted wireless signal **110** and provides a received signal **112** to the conventional power detector **104** and the LNA **106**. The LNA **106** amplifies the received signal **112** and provides an amplified received signal **116** to the tuner **108**. The transmitted wireless signal **110** and the received signal **112** are typically radio frequency (RF) signals.

The tuner **108** operates optimally when the amplitude of the amplified received signal **116** is constant. The variable gain of the LNA **106** is adjusted to compensate for fluctuations in the amplitude of the received signal **112** to provide an amplified received signal **116** having constant amplitude. The variable gain of the LNA **106** is properly adjusted through the use of the conventional power detector **104**. The conventional power detector **104** measures the amplitude or power of the received signal **112** and produces a voltage signal **114** as an indication of the measurement. The voltage signal **114** is provided to the LNA **106**. The variable gain of the LNA **106** can be precisely set based on the voltage signal **114** to provide the amplified received signal **116** having constant amplitude.

The precision of the conventional power detector **104** largely determines the precision of the gain adjustment by the LNA **106**. Therefore, it is desirable to eliminate variations in the voltage signal **114** caused by frequency, process and temperature.

FIG. **2** illustrates an implementation of the conventional power detector **104**. As shown, the conventional power detector **104** includes an RF preamplifier **202**, a conventional rectifier **204** and a low frequency (LF) amplifier **206**. The RF preamplifier amplifies the incoming received signal **112** (shown in FIG. **2** as differential received signals **112**-*a* and **112**-*b*). The RF preamplifier provides amplified received signals **208**-*a* and **208**-*b* to the conventional rectifier **204**. The conventional rectifier **204** converts the amplified received signals **208**-*a* and **208**-*b* from differential RF signals to differential DC output signals **210**-*a* and **210**-*b*. The differential DC output signals **210**-*a* and **210**-*b* are provided to the LF amplifier **206**. The LF amplifier amplifies the differential DC output signals **210**-*a* and **210**-*b* to produce the voltage signal **114** (shown in FIG. **2** as differential voltage signals **114**-*a* and **114**-*b*).

The precision of the conventional power detector **104** is largely influenced by the linearity of the conventional rectifier **204**. Therefore, it is desirable for the conventional rectifier **204** to provide a linear change in output voltage for a linear variation in the amplitude of an input signal.

FIG. **3** illustrates an implementation of the conventional rectifier **204**. The conventional rectifier **204** includes rectifier transistors **312** and **314** and a reference transistor **316**. The rectifier transistors **312** and **314** and the reference transistor **316** are Bipolar Junction Transistors (BJTs). The rectifier transistors **312** and **314** and the reference transistor **316** are of the same small unit size. The collectors of the rectifier transistors **312** and **314** and the collector of the reference transistor **316** are connected to a supply voltage V_{SUPPLY}. The base of the rectifier transistor **312** is AC coupled to the amplified received signal **208**-*a* through a capacitor **302**. The base of the rectifier transistor **312** is DC coupled to a bias voltage V_{BIAS} through a resistor **306**. Similarly, the base of the rectifier transistor **314** is AC coupled to the amplified received signal **208**-*b* through a capacitor **304** and is DC coupled to V_{BIAS} through a resistor **308**. Further, the base of the reference transistor **316** is DC coupled to V_{BIAS} through a resistor **310**.

The bias voltage V_{BIAS} and the resistors **306**, **308** and **310** form a bias network for the transistors **312**, **314** and **316**. Typically, the resistors **306**, **308** and **310** have equal resistances to provide the same biasing to the bases of the rectifier transistors **312** and **314** and to the base of the reference transistor **316**. Further, the resistances of the resistors **306**, **308** and **310** are typically large to isolate the bias network from the RF input signals (i.e., the amplified received signals **208**-*a* and **208**-*b*).

As further illustrated in FIG. **3**, the emitters of the rectifier transistors **312** and **314** are connected together and provide the DC output signal **210**-*a*. A current source **318** provides a bias current I_{BIAS} to the emitters of the rectifier transistors **312** and **314**. The emitters of the rectifier transistors **312** and **314** are coupled to a capacitor **322**. Typically, the capacitor **322** has a large capacitance. The capacitor **322** forms a resistor-capacitor (RC) filter with either an inherent emitter resistance of the rectifier transistors **312** and **314** or with a resistance from a load connected to the emitters of the rectifier transistors **312** and **314**.

The emitter of the reference transistor **316** provides the DC output signal **210**-*b*. The emitter of the reference transistor **316** is biased by a current source **320** that provide a bias current $I_{BIAS}/2$. Further, the emitter of the reference transistor **316** is coupled to a capacitor **324** that typically has a large capacitance. The capacitor **324** forms an RC filter with either an inherent emitter resistance of the reference transistor **316** or with a resistance from a load connected to the emitter of the reference transistor **316**. Capacitor **324** also improves the interference immunity of the DC output signal **210**-*b*.

During operation, the conventional rectifier **204** produces a DC output voltage that is proportional to the amplitude of the differential input signal received by the conventional rectifier **204**. Specifically, the difference between the DC output signal **210**-*a* and **210**-*b* is a DC output voltage that is proportional to the amplitudes of the amplified received signals **208**-*a* and **208**-*b*.

The rectifier transistors **312** and **314** rectify the differential amplified received signals **208**-*a* and **208**-*b* and provide a first component of the DC output voltage (i.e., the DC output signal **210**-*a*). The DC output signal **210**-*a* is averaged by the RC filter connected to the emitters of the rectifier transistors **312** and **314**. The DC output signal **210**-*a* includes a DC voltage proportional to the amplitudes of the amplified received signals **208**-*a* and **208**-*b* and an offset voltage. The offset voltage is the result of the biasing of the rectifier transistors **312** and **314**, which is needed to establish the rectifying operation of the rectifier transistors **312** and **314**.

The reference transistor **316** provides a second component of the DC output voltage (i.e., DC output signal **210**-*b*). The DC output signal **210**-*b* is a reference voltage approximately equal to the offset voltage of the DC output signal **210**-*a*. Therefore, subtracting the DC output signal **210**-*b* from the DC output signal **210**-*a* cancels the offset voltage such that the conventional rectifier **204** provides a DC output voltage that is proportional to the amplitude of the differential input signal received by the conventional rectifier **204**.

The precision of the conventional rectifier **204** is limited by linearity errors and process and temperature variations. A linear RF rectifier produces an output voltage that increases at a constant rate as the RF input signal amplitude is increased. A BJT arranged in a common-collector configuration exhibits strong linear behavior and so is typically used for the rectifier transistors **312** and **314** and the reference transistor **316**. Further, process variations between similar circuit elements of the conventional rectifier **204** can be made small by limiting random mismatches between constituent circuit elements. However, absolute process and temperature variations can still significantly limit the precision of the conventional rectifier **204**. For example, when the conventional rectifier **204** is implemented within an Automatic Gain Control (AGC) loop, undesirable gain loops or ripples can be introduced as temperature varies.

The conventional rectifier **204** exhibits an especially strong dependence on temperature at low input power levels. The strong temperature dependence of the conventional rectifier **204** is largely the result of the BJTs used to implement the conventional rectifier **204**. The DC current versus voltage (I-V) characteristics of BJTs are temperature dependent. Therefore, as temperature varies, the output voltage of a BJT varies considerably for a given constant input current. In turn, the measurement performance of the conventional power detector **204** suffers. This temperature dependence also limits the range of input amplitudes that can be accurately measured by the conventional power detector **204** to relatively high levels where the effects of temperature variation are less pronounced. Further, RF input bandwidth is limited if low power input signals require higher RF gain prior to power detection.

It is therefore desirable to reduce or eliminate the temperature dependence of a power detector to improve measurement precision. Specifically, it is desirable for a power detector to have temperature compensation so as to improve RF input bandwidth, expand acceptable input amplitude range, and reduce measurement inaccuracy.

FIG. **4** illustrates a rectifier **400** of the present invention having temperature compensation for improved measurement performance. The rectifier **400** is used within a power detector to minimize or reduce output temperature dependence. The rectifier **400** includes an offset current source **402** that generates an offset current I_{OFFSET}. The offset current source **402** is connected to the emitter of the reference transistor **316**. The offset current I_{OFFSET} is constant over temperature (CAT) or temperature independent. The offset current I_{OFFSET} exploits the inherent temperature dependence of the BJT I-V characteristic so as to cancel, to first order, the variation introduced by temperature.

The offset current I_{OFFSET} adds to the biasing of the reference transistor **316**. In turn, variations in the output of the rectifier **400** caused by temperature are canceled to first order to provide a more precise output for use in a power detector. In this way, the BJT dependence on temperature ceases to be the dominant error factor of the rectifier **400**, even at low input power levels. The precision of the rectifier **400** therefore only remains limited to process variation and nonlinearity.

The rectifier transistors **312** and **314** and the reference transistor **316** each have an inherent temperature coefficient governed by the laws of physics and determined by fabrication. The temperature coefficient of each transistor is a measure of the output temperature dependence for each transistor. Each temperature coefficient can be made small and approximately equivalent by sizing the rectifier transistors **312** and **314** and the reference transistor **316** to be small and of equal size. In turn, the temperature dependence of the output of the rectifier transistors **312** and **314** and the reference transistor **316** for a given input is approximately equal.

This similar temperature dependence, however, can vary as the biasing and operation of each transistor varies. To maintain similar biasing, each terminal of the rectifier transistors **312** and **314** and the reference transistor **316** are biased with equal DC voltages and currents. During operation, however, the bases of the rectifier transistors **312** and **314** are driven harder than the base of the rectifier transistor **316** due to the amplified received signals **208**-*a* and **208**-*b*, respectively. That is, the AC input signals (i.e., the amplified received signals **208**-*a* and **208**-*b*) enhance the effects of the temperature dependence of the rectifier transistors **312** and **314**. The effects of the temperature dependence of the reference transistor **316** are not similarly enhanced during operation since the reference transistor **316** is only biased by DC currents and voltages and is not driven by an AC input signal.

The increased temperature dependence of the rectifier transistors **312** and **314** causes the constant base-to-emitter voltage drops ($V_{BE,312}$ and $V_{BE,314}$) to differ from the constant base-to-emitter voltage drop ($V_{BE,316}$) of the reference transistor **316**. When $V_{BE,316}$ differs from $V_{BE,312}$ and $V_{BE,314}$, the difference signal produced by subtracting the DC output signals **210**-*a* and **210**-*b* from one another is a less accurate measurement of the amplitude of the RF input signal (i.e., the amplified received signals **208**-*a* and **208**-*b*). Specifically, the reference voltage provided by the DC output signal **210**-*b* will no longer approximately equal the offset voltage component of the DC output signal **210**-*a*.

To improve the measurement accuracy of the rectifier **400**, the offset current source **402** is used to provide temperature compensation. The offset current source **402** boosts the biasing of the reference transistor **316** such that $V_{BE,316}$ more closely follows changes to $V_{BE,312}$ and $V_{BE,314}$ during operation. In this way, the offset current source can be adjusted such that the reference voltage of the DC output signal **210**-*b* is substantially equal to the offset voltage of the DC output signal **210**-*a*. In turn, the difference signal generated by subtracting the DC output signal **210**-*b* from the DC output signal **210**-*a* is a more accurate measure of the amplitudes of the amplified received signals **208**-*a* and **208**-*b*. Specifically, the measurement performance of the rectifier **400** is improved with respect to the measurement performance of the rectifier **300** depicted in FIG. **3**.

The offset current I_{OFFSET} generated by the offset current source **402** can be made independent of temperature by placing the offset current source **402** off-chip. Specifically, the current source **402** can be referenced to an external resistor that is not susceptible to temperature fluctuations experienced by the other circuit elements of the rectifier **400**. In contrast, the current sources **318** and **320** are temperature dependent since they are generated on-chip. Specifically, the current sources **318** and **320** are referenced to a local resistor that is susceptible to the temperature fluctuations experienced by the other circuit elements of the rectifier **400**.

The scaling of the offset current I_{OFFSET} generated by the offset current source **402** is determined by the amount of temperature dependence correction required. For example, the offset current I_{OFFSET} can be chosen based on the expected range of power levels of the amplified received signals **208**-*a* and **210**-*b*. Alternatively, the offset current I_{OFFSET} can be kept constant at a level that is optimized for a given input power. In one embodiment, the offset current I_{OFFSET} can be set approximately equal to $2 \cdot I_{BIAS}$ under nominal temperature and process conditions to provide an appropriate temperature dependence correction.

The temperature compensation of the rectifier **400** provided by the present invention enables a power detector to produce more accurate amplitude or power measurements of input signals. Further, the temperature compensation technique provided by the present invention can improve RF input bandwidth and expand the acceptable input amplitude range. Overall, the temperature compensation provided by the present invention prevents dependence on temperature from being the dominant error factor during operation of a power detector.

FIG. **5** illustrates a rectifier **500** of the present invention that uses feedback to provide temperature compensation for improved measurement performance. The rectifier **500** includes an adjustable current source **502** that is a constant current over temperature (CTAT). The adjustable current source **502** provides an adjustable offset current I_{OFFSET}. The adjustable current source **502** is adjusted during operation of the rectifier **500** by a feedback circuit **504**. The feedback circuit **504** is coupled to the output of the rectifier **500**. The feedback circuit **504** measures the difference between DC output signals **210**-*a* and **210**-*b* and adjusts the adjustable current source **502** based on the detected output amplitude.

FIG. **6** provides a flowchart **600** that illustrates operational steps corresponding to FIG. **5** for adjusting a CTAT offset current of a rectifier to provide temperature compensation for improved measurement performance, according to the present invention. The invention is not limited to this operational description. Rather, it will be apparent to persons skilled in the relevant art(s) from the teachings herein that other operational control flows are within the scope and spirit of the present invention. In the following discussion, the steps in FIG. **6** are described.

At step **602**, a differential input signal is received. The differential input signal can be a baseband or RF input signal.

At step **604**, a pair of rectifier transistors are biased using a temperature dependent current source.

At step **606**, the differential input signal is rectified using the pair of rectifier transistors to provide a first component of a differential DC output signal. The first component of the differential DC output signal comprises a DC voltage proportional to an amplitude of the differential input signal plus an offset voltage.

At step **608**, a reference transistor is biased using a reference current generated by a temperature dependent current source and a temperature independent current source to provide a second component of a differential DC output signal. The second component of the differential DC output signal comprises a reference voltage.

At step **610**, a difference signal is generated by subtracting the second component of the differential DC output signal from the first component of the differential DC output signal.

At step **612**, the temperature independent current source is adjusted based on the difference signal such that the second component of the differential DC output signal is substantially equal to the offset voltage of the first component of the differential DC output signal. Specifically, a CTAT current provided by the temperature independent current source is adjusted so that the reference voltage is substantially equal to the offset voltage. In turn, the difference signal provides a more accurate measurement of the amplitude of the differential input signal since the CTAT offset current effectively counteracts the temperature dependence of the rectifier.

At step **614**, the difference signal is monitored during operation of the rectifier. The CTAT offset current source is adjusted based on the difference signal in order to provide an accurate measure of the amplitude of the differential input signal.

In the foregoing description, embodiments of the present invention are described as including BJTs. The present invention, however, is not limited to embodiments using BJTs. That is, other processes and transistor structures could be used as will be understood by those skilled in the relevant arts, based on the discussion given herein. For example, Metal-Oxide Semiconductor Field-Effect Transistors (MOSFETs) can be used to realize the present invention. Using MOSFETs may require the use of a variable offset current. Further, the present invention is not limited to use within the circuits described herein. That is, the present invention can be used in a variety of circuits to provide a more accurate power measurement of an input signal. For example, the present invention can be used in AGC loops, automatic amplitude control loops, quadrature calibration circuitry or any other circuit that performs RF amplitude measurements, as commonly found in RF receivers and transmitters.

CONCLUSION

While various embodiments of the present invention have been described above, it should be understood that they have been presented by way of example and not limitation. It will be apparent to one skilled in the pertinent art that various changes in form and detail can be made therein without departing from the spirit and scope of the invention. Therefore, the present invention should only be defined in accordance with the following claims and their equivalents.

What is claimed is:

1. A power detector, comprising:

a pair of rectifier transistors coupled to a differential input signal and biased by a first temperature dependent current;

a capacitor coupled to an output of the pair of rectifier transistors to provide a first component of a differential DC output signal; and

a reference transistor biased by a reference current and having an output to provide a second component of the differential DC output signal;

wherein the reference current comprises a second temperature dependent current and a temperature independent offset current.

2. The power detector of claim **1**, wherein:

the first component of the differential DC output signal comprises a DC voltage proportional to an amplitude of the differential input signal plus an offset voltage; and

the second component of the differential DC output signal comprises a reference voltage.

3. The power detector of claim **2**, wherein the temperature independent offset current is adjusted such that the reference voltage is substantially equal to the offset voltage.

4. The power detector of claim **3**, wherein the temperature independent offset current is adjusted based on an expected range of the amplitude of the differential input signal.

5. The power detector of claim **3**, wherein the temperature independent offset current is set at a constant level based on a constant input power level of the differential input signal.

6. The power detector of claim **3**, further comprising a feedback circuit to adjust the temperature independent offset current.

7. The power detector of claim **6**, wherein the feedback circuit is coupled to the output of the pair of rectifier transistors and the output of the reference transistor.

8. The power detector of claim **7**, wherein the feedback circuit adjusts the temperature independent offset current based on a difference between the first component of the differential DC output signal and the second component of the differential DC output signal.

9. The power detector of claim **1**, wherein the second temperature dependent current is a fraction of the first temperature dependent current.

10. The power detector of claim **9**, wherein the second temperature dependent current is approximately one-half of the first temperature dependent current.

11. The power detector of claim **1**, wherein the temperature independent offset current is generated by an external current source.

12. The power detector of claim **1**, wherein each transistor comprises a Bipolar Junction Transistor (BJT).

13. The power detector of claim **1**, wherein each transistor comprises a Metal Oxide Semiconductor Field-Effect Transistor (MOSFET).

14. The power detector of claim **1**, wherein the differential input signal is a differential radio frequency (RF) signal.

15. A method for measuring the amplitude of a differential input signal, comprising:

(1) biasing a pair of rectifier transistors with a first temperature dependent current source;

(2) rectifying a differential input signal using the pair of rectifier transistors to provide a first component of a differential DC output signal; and

(3) biasing a reference transistor using a reference current to provide a second component of the differential DC output signal;

wherein the reference current comprises a second temperature dependent current and a temperature independent offset current.

16. The method of claim **15**, further comprising the step of:

(4) generating a difference signal proportional to an amplitude of the differential input signal by subtracting the second component of the differential DC output signal from the first component of the differential DC output signal.

17. The method of claim **16**, wherein step (3) further comprises

(a) adjusting the temperature independent offset current based on the difference signal such that the second component of the differential DC output signal is substantially equal to an offset of the first component of the differential DC output signal.

18. A power detector, comprising:

a pair of rectifier transistors coupled to a differential input signal and biased by a first temperature dependent current, wherein an output of the pair of rectifier transistors provides a first component of a differential DC output signal; and

a reference transistor biased by a reference current, wherein an output of the reference transistor provides a second component of the differential DC output signal;

wherein the reference current comprises a second temperature dependent current and a temperature independent offset current.

19. The power detector of claim **18**, wherein:

the first component of the differential DC output signal comprises a DC voltage proportional to an amplitude of the differential input signal plus an offset voltage; and

the second component of the differential DC output signal comprises a reference voltage substantially equal to the offset voltage.

* * * * *